The radius of hole teleportation and quantum teleportation is limited by Hubble sphere

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Abstract: The maximal distance of hole teleportation and quantum teleportation is limited by cosmological expansion and cannot exceed the Hubble's radius (c/H_0) ~ 13 billions of light years. Entanglement depends on the distance, there is ultimate, fundamental and insuperable distance for teleportation as Hubble sphere. Besides quantum teleportation is limited by anthropic barrier 1 - 100 parsec.
- The radius of quantum and hole teleportation depends on speed of movement, the more speed, the more the radius of teleportation.
- The space around teleporter can be divided in three zones: 1) A green zone (sphere) where teleportation is allowed without any conditions; 2) There is yellow zone between Green and Hubble spheres, conditionally allowed for teleportation, where for teleportation is necessary to satisfy additional conditions. 3) There is red zone forbidden for teleportation outside of Hubble sphere.

Keywords: Green zone, Hubble sphere, acceleration, uniform rectilinear motion, cosmological expansion, superluminal photons, human teleportation.

The finite radius of hole teleportation

There are two opportunities to find the radius of hole teleportation:
1) Proceeding from definition of hole teleportation as a superanalogue of uniform rectilinear movement;
2) The radius of hole teleportation is limited by laws of conservation, or by principle of the stable universe;

By definition, hole teleportation is a superanalogue of uniform rectilinear movement. At teleportation the object can appear only on its trajectory of uniform rectilinear motion. Consequently, to find out the radius of hole teleportation it is enough to measure the length of the object's trajectory of uniform rectilinear movement. If the length of the trajectory of uniform rectilinear movement will be infinite (at ideal conditions, when other material bodies and fields are far enough from a trajectory), then the radius of hole teleportation also will be infinite. If the movement of object at certain distance from point A ceases to be uniform and rectilinear, then the radius of teleportation also will be finite.

The measurement of length of uniform rectilinear trajectory

Let the body M moves slowly by inertia from point A into deep space, the influence of external forces is considered neglectful small. Both observers A and M are equipped with the synchronized clocks; the M also is equipped with a source of light signals emitted out through equal intervals of time by onboard clocks. The purpose is to determine if the motion of body is uniform and rectilinearly by calculating the distance passed during equal intervals of time. Though there is more simple method as Doppler effect to control the speed of body M. In addition, it is necessary to check if the trajectory of motion of body by inertia is rectilinear, for example by measuring the corners of a triangle.

After some time the observer from A will notice the redshift of light signals from M because of cosmological expansion, that is the proof that the speed of body M has changed, and its movement is not more uniform rectilinear. For example at distance 100 Mpc from A, the body M will receive additional speed near 7000 - 8000 km/s. Thus, the movement of bodies can be

uniform rectilinear only on small distance Rg from the start point, where cosmological expansion is sufficiently small and unnoticeably. Therefore, unconditional teleportation of bodies also is possible only inside of sphere with radius Rg.

The laws of energy conservation limit the radius of teleportation

Let us determine the radius of teleportation by the analysis of energy release at teleportation. Suppose we teleport the object M from volume A to volume B on distance R=100 Mpc. According to the impulse conservation law and definition of hole teleportation as superanalogue of uniform rectilinear motion, after materialization in volume B the object M should have the same speed and direction of movement concerning start point A (with the accuracy allowed by uncertainty principle). In other words, after teleportation the body M should appear in the same reference frame and on the same trajectory of uniform rectilinear motion. However, because of cosmological expansion, the matter around the object M moves in the radial direction with the velocity H0R ~ 7000 - 8000 km\sec. It means that after materialization the object M will move concerning local matter with the speed ~ 7000 - 8000 km/sec in the direction of A. Now we slow down the object M concerning local planets or stars, transforming the kinetic energy of object M in thermal or electric energy. When the object will be at rest concerning the local matter, let we teleport the object back to volume A, or to any other place located at distance R>100 Mpc. In the new place body M will have again the velocity of ~ H0R= 7000 - 8000 km\sec relative surrounding matter. Then we again slow down the speed, converting the kinetic energy into thermal energy, until the object M will be at rest concerning local matter. Thus this process of teleportation at long distances (100 Mpc) can be repeated indefinitely, and each time with considerable energy release "from nothing". Whence this energy appear? It is energy of cosmological expansion of the universe, and this energy release at long-distance teleportation (R>Rg) will appear until universe stop the expansion. Thus long-distance teleportation (R>Rg) acts against expansion of universe and must be forbidden, for example by the principle of stable universe. This principle forbids all processes that can change universe as the whole or at least its large-scale parts. Since by definition for teleportation as uniform rectilinear movement of objects from one place to another is not necessary energy expenditure, the process of energy release at teleportation is very suspicious and signals that teleportation at long distance (R>Rg) violates the laws of nature and must be forbidden. Thus teleportation is allowed inside of green (Euclidean) sphere only, where cosmological expansion is sufficiently small and do not perturb the motion by inertia. Except for above listed arguments, there are special relativity effects, as Lorentz contraction, mass increase, and time dilation, which forbid teleportation outside of green sphere. For example, because of Lorentz contraction the hole spheres in start and destination places may have different sizes, that forbid the inversion (exchange of volumes). In addition, the teleported object may have different masses in start and destination places that are violation of conservation laws. However, all these problems disappear if teleportation is allowed inside of green zone only and is forbidden outside of green zone.

Euclidean sphere or green zone Rg allowed for teleportation

Green zone Rg is the space around teleporter where the motion of bodies is true uniform and rectilinear, due to teleportation is allowed without any additional conditions inside of green sphere Rg. For an ideal case when the reference frame Rg is fixed concerning microwave background radiation, the green zone is the correct sphere with radius roughly Rg ~ 1 - 1000 parsec. The value of Rg depends on the minimal speed between two frames when teleportation of material bodies between them is still possible. In order to find the exact experimental value of Rg, it is possible to use the following hypothesis: above was discussed the question if the motion of body is uniform at long distances only, but not if it is also rectilinear. For exact experimental measurement of Rg, we can use the following hypothesis: above was discussed only the question

about uniform motion of object but not rectilinear; Thus, we must check up if the trajectory of motion by inertia at cosmologically big distances is rectilinear (straight line) in cense of a three dimensional Euclidean geometry. In other words, it means that we must check if the geometry of large distance scale is three dimensional and Euclidean. There is suspicion that at scale (distance) R>Rg the motion of body by inertia is neither uniform nor rectilinear in cense of three dimensional Euclidean geometry, that can be verified by measuring the corners of a triangle constructed on trajectory of motion of body by inertia.

There is no data in references about changes of geometry at large scales ~ 1 – 1000 parsec, that can be explained by that space expansion is uniform in all directions due to changes of geometry at large scales is imperceptible for observers because it seems to them the light from stars moves on straight lines. If to expand an elastic rubber band with straight lines from stars and a triangle, the observer will see light coming from stars on straight lines, but the sum of angles of triangle can differ. Thus, from my point of view the space is 3-dimensional and Euclidean only at short distances inside of green sphere and at the large scales (R>Rg) the geometry of space may be 4-dimenional or non-Euclidean.

The green zone Rg (Euclidean sphere) is the three dimensional Euclidean space where the motion by inertia is uniform and rectilinear in cense of three dimensional Euclidean geometry, due to teleportation is allowed without any additional conditions.

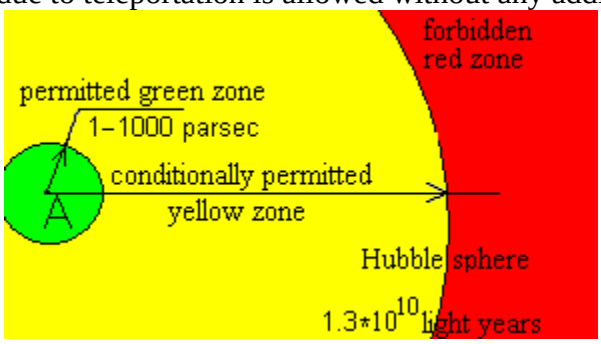

Figure 1. Green, yellow and red (forbidden) zone around teleporter in point A

The yellow zone conditionally allowed for teleportation is limited by Hubble sphere

Let's analyze the question how to teleport objects outside of green zone into yellow zone, proceeding from two arguments: a) from the analysis of how it is possible to remove the obstacles at long distance teleportation described above; b) Let's analyze how a material body moving by inertia can reach the cosmologically distant point by uniform rectilinear motion.

a) All obstacles described above for teleportation at cosmologically long distances disappear, if to accelerate the object before teleportation in order to equal its speed with the real speed of cosmological expansion of destination galaxy (matter). The energy "from nothing" do not appear, if at materialization the body will be at rest relative to local matter in destination place, or its radial speed will exceed the speed of cosmological expansion of local matter in destination place. For example, let us teleport a body on distance 100 Mpc, where galaxies recede with the speed ~ H0R= 7000 - 8000 km/sec. In this case the teleportter must have the speed $V = H_0R + v2$, where v2 is the correction coefficient considering changes of distance up to the destination place and the speed of cosmological expansion of matter during movement of light to the observer, equal to 326 million years. In addition, the speed vector should be directed precisely on the destination place (if space at large scales are three dimensional and Euclidean only). Thus, now all the necessary parameters for teleportation (speed and time rate) are the same in both start and finish volumes. It means that now in destination galaxy appeared a part of trajectory of uniform rectilinear motion. After materialization in that galaxy (100 Mpc), the radial speed of

body will be equal to zero or bigger relative the radial speed of cosmological expansion of matter in destination place (peculiar speeds are not important). In this case, the energy from nothing does not appear that allow teleportation outside of green zone.
b) The scheme for long distance teleportation can be found by analyzing a simple inertial motion of the body at cosmologically long distances. How the material body can reach a cosmologically distant point? It is known, that kinetic energy or wavelength of all particles continuously decreases because of cosmological expansion. At propagation of light in expanding Universe, the wavelength of photons increases (redshifts). Also material bodies moving on cosmologically long distances lose the speed. Only in cosmology can be situation when the galaxy moving with the big speed to us actually recede because of cosmological expansion. Thus the body can reach distant galaxy moving by inertia only if its speed is equal or bigger than some limiting velocity Vlim ($>H_0R$), where Vlim is minimal speed for body to reach distant galaxy. Thus if the initial speed of body is Vlim, then its radial speed at destination galaxy will be equal to zero because of cosmological expansion.
By analogy, the teleportation scheme repeat this simple scenario of motion of body by inertia at cosmologically big distances, that means teleportation is superanalogue of uniform rectilinear motion and it respect cosmological laws. (Except for the fact that the transfer time in teleportation from A to B is equal to zero because there is not necessary to consider increasing in distance and speed between A and B during the time of mechanical motion of body). Therefore the speed of teleporter may be less than Vlim for case of inertial motion of body, but we must consider real speed of cosmological expansion of destination galaxy at the moment of teleportation. The maximal radius for Hole Teleportation is calculated by Hubble's formula:

$$\mathrm{R(Mpc)}=\frac{\mathrm{V}}{\mathrm{H0}}+\mathrm{Rg}\sqrt{1-V^2/c^2}$$

where V is the speed of object, H_0 – Hubble constant, Rg – the radius of green (Euclidean) sphere.

Since the speed V is limited by speed of light, there is a limiting distance for teleportation – Hubble's radius c/H_0 ~ 13 billions of light years. Outside of Hubble sphere is red zone forbidden for teleportation. The maximal radius of hole teleportation continuously decrease because of the accelerated expansion of the Universe, and now it is equal to the radius of Hubble's sphere ~ $1.3*10^{10}$ light years. The radius of green sphere also continuously decreases because of accelerated expansion of universe. Thus in very far future the radius of hole teleportation will be shorter than in present. Since Earth move relative microwave background radiation, the maximal radius for hole teleportation from the Earth in direction of apex may be about ~ 5 - 9 Mpc. The radius of hole teleportation depends on the speed, the more is the speed, the more is the radius of teleportation.

There is an interesting coincidence (about levitation in hole vacuum). As if knowing about that for teleportation at long distances is necessary acceleration, nature supplied hole teleporter by levitating ability, in order to simplify the long-distance teleportation. It simplifies the construction of teleporter, because disappears the necessity to equip teleporter with additional engines for acceleration. Now it is enough to create unclosed hole surface around spacecraft ant it will move with very large acceleration without forces of inertia. After spacecraft (teleporter) reach the necessary velocity, hole surface closes and one is teleported at long distance, up to 13 billions of light years.

Hubble sphere limit the radius of quantum teleportation

Since quantum teleportation use quantum and classical channels and it is necessary to deliver

the entangled particles to destination, each of the listed below factors can limit the radius of quantum teleportation:
1) The radius of quantum channel (the maximal distance of delivery of quantum information).
2) The radius of classical channel (the maximal distance of delivery of classical information).
3) The radius of delivering of the entangled particles (the maximal distance of delivery of entangled EPR particles).

At studying of the nature of teleportation the fundamental interest presents mainly the radius of the quantum channel, which most likely, has the same nature, as hole teleportation, because in both cases the material object or its quantum state is transferred from one place to another, without passing through the intervening space, i.e. outside of space - time, through vacuum hole. Since last two factors are less fundamental for nature of teleportation we will consider its radius equal to the radius of quantum channel. Nevertheless, the radius of last two factors is limited, for example by anthropic (human) barrier, because humans cannot wait, for example 326 million years, while the classical part of the information will be delivered from Alice to Bob, on distance 100 Mpc. Because human life is very short in comparison with cosmological distances and time needed to pass one. Therefore, actually the radius of quantum teleportation is limited by anthropic barrier ~ 1 – 100 parsec, but since we study the radius of the quantum channel, it is possible to count conditionally, that technical problems can be excluded, including radiuses of last two factors at least equal to limiting radius of a quantum channel.

The green (Euclidean) sphere for quantum teleportation using entangled massless particles (photons)

Let we have a source that emits pairs of entangled photons, with one photon sent to destination A (to sender Alice), and another is sent to destination B (to receiver Bob) (see figure below).

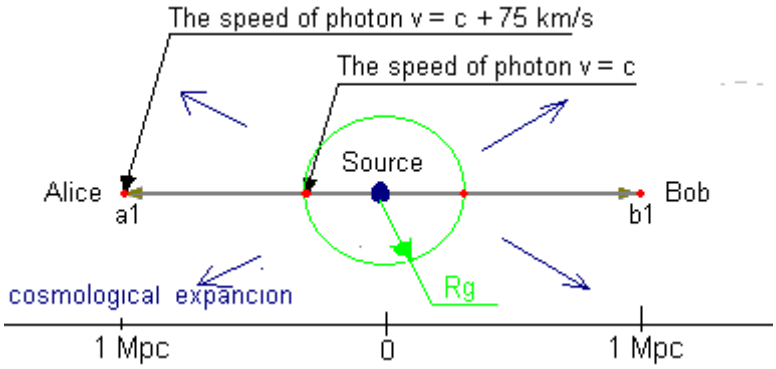

Figure 2. Cosmological expansion increase the speed of photons outside of green sphere (superluminal photons).

Thus, two entangled photons fly from source to opposite directions, to Alice and Bob respectively. Pay attention that near source the speed of photons is strongly equal to the speed of light v = c, but at distance 1 Mpc the speed of photon relative source will be $v = c + H_0R = C + 75$ km/sec, (H_0 – Hubble constant, R- distance) because of cosmological expansion. Also the speed of Alice's photon relative Bob will be v= c + 150 km/sec. Thereby, the speed of entangled photon c + 75 (150) km/sec exceeds the speed of light relative source and one of observers. It do not violate relativity, because photons move together with expanding space, and locally the speed of photons are equal to c, but quantum teleportation by help of superluminal photons is in doubt.
Relativity forbid superluminal motion, but if exist exceptions, for example as superluminal

galaxies, then these objects must be in total isolation from each other. It means communication is forbidden with the objects that move faster than light. There are no experimental examples of communication between objects that move faster than light. For example, the photon a1 moves with the speed c+150 km/sec relative Bob (and its measuring device, and twin photon b1), therefore these objects must be in total isolation one from another, and no communication is possible between them, including quantum teleportation. Thus quantum teleportation is allowed only inside of small sphere with radius Rg (green zone), where cosmological expansion is very small (negligible), and quantum teleportation is carried out in standard conditions, when the speed of photons relative observers and measuring devices is equal to the speed of light in vacuum. Pay attention, that the value of green zone Rg for both quantum and hole teleportation is the same (1- 1000 parsec), because it is enough to add some meters per second to the speed of photon, and it will be the superluminal speed already. In other words, for entangled photons the green sphere can be named the small Hubble sphere, because in both cases outside of these spheres objects move faster than light.

How to teleport the quantum state outside of green sphere (at distances R>Rg)

The solution for long distance quantum teleportation is the same as for hole teleportation: we must eliminate the effects of cosmological expansion. It is enough to accelerate one of observers together with its measuring devices in the direction of another observer, until its radial speed will be v = H0R (R is the distance to another observer), and the speed of opposite photon ceases to be superluminal relative observers, that allow quantum teleportation. For example, for described above case (Fig. 2), Alice must increase its speed by 150 km/sec in direction to Bob, in order to eliminate cosmological effects and enable quantum teleportation.

Nevertheless, remain another problem: the speed between entangled photons a1 and b1 outside of green sphere (1 Mpc) exceed the speed between the same photons inside of green sphere, that me disable quantum teleportation. Therefore, long distance teleportation outside of green zone will be possible only if we'll be able to slow down photons without decoherence. In this case the radius of quantum teleportation depend on speed in the same way as hole teleportation. The radius of quantum teleportation will be:

$$\mathrm{R(Mpc)}=\frac{\mathrm{V}}{\mathrm{H0}}+\mathrm{Rg}\sqrt{1-V^2/c^2}$$

Since the speed V is bounded by c — the velocity of light, there is insuperable distance (barrier) for quantum teleportation as Hubble sphere. Quantum teleportation is bounded by Hubble sphere, and it is ultimate, insuperable and fundamental barrier. If the distance between Alice and Bob (together with its entangled particles) is equal or exceed the Hubble radius Rh, then following effects forbid quantum teleportation:

1. The speed of material objects is bounded by velocity of light, therefore teleportation beyond the Hubble sphere is forbidden by special relativity.
2. Lorenz contraction: Since the speed of entangled particles relative each other exceed the speed of light, then particles cancel to be entangled, because the wavelength of one particle do not have physical sense relative another. Therefore particles cannot be described by the same wavefunction, because wavelength it are another particle.
3. Because Universe expands with acceleration, the classical part of information from Alice cannot be delivered to Hubble sphere (to Bob, or vice versa), due to quantum teleportation is not possible.
4. Time dilation: Since the speed of Alice relative Bob is equal or exceeds the speed of light, the time rate between Alice and Bob do not have sense, and they cannot compare its clocks. Therefore, instant reduction of wavefunction between them is impossible.

Thus in case R > Rh both quantum channel, nor classical channel does not work, and we cannot

deliver entangled particles to (outside of) Hubble sphere, because particles cancel to be entangled.

Limitation of radius of teleportation is in agreement with the quantum mechanics

Quantum mechanics allow the limitation of radius of quantum teleportation, because it does not allow simultaneous measurement of conjugate quantities. If in EPR paradox instant reduction of wavefunction appear in order to prevent the simultaneous measurement of certain conjugate quantities (for example position and momentum), which are pairs of observables of a single elementary particle, then outside of green sphere appear another phenomenon which forbid simultaneous measurement of conjugate quantities as relativistic effects (Lorentz contraction, time dilation, mass increase). Thus outside of green sphere instead of instant reduction of wavefunction appear relativistic effects, and simultaneous measurement of conjugate quantities is not possible. But if we increase the speed of observers in order to eliminate the cosmological expansion, then relativistic effects disappear and reappear instant reduction of wavefunction, which enables quantum teleportation.

The definition of quantum teleportation needs to be changed, by removing words “an arbitrarily distant location” that is incorrect, since the distance of teleportation is limited by fundamental factors. Instead of old definition:
Quantum teleportation, or entanglement-assisted teleportation is a technique that transfers a quantum state to an arbitrarily distant location using a distributed entangled state and the transmission of some classical information.
There is new definition of quantum teleportation:
Quantum teleportation, or entanglement-assisted teleportation is a technique that transfers a quantum state up to finite distance Rg (green zone) but not further Hubble sphere, using a distributed entangled state and the transmission of some classical information.

The radius of quantum teleportation using massive entangled particles

Since hole teleportation teleport material objects, its radius is limited by energy (impulse) conservation laws. The radius of quantum teleportation using massless entangled particles is limited by special relativity, because outside of green sphere photons move faster than light. What can limit the radius of quantum teleportation using massive entangled particles? (Considering that it is teleportation of quantum state only, and the speed of massive entangled particles is less than the speed of light) There is a suspicion, that relativistic effects can limit the radius of quantum teleportation using massive entangled particles. Nevertheless, since there is opinion in references that relativistic effects on entanglement will not be dominating [1] and the entanglement is Lorentz invariant [2], due to all factors able to limit the radius of teleportation disappears. Thus, in case that entanglement is Lorentz invariant, then quantum teleportation using massive entangled particles will not have fundamental bounds inside of Hubble sphere (except for anthropic barrier 1 – 100 parsec). Although all present investigations of quantum entanglement measured in an inertial frame moving with relativistic speed are theoretical only and therefore can be erroneous. In this case, quantum teleportation is limited in the same way by green, yellow and red zone. There are signs that quantum entanglement is not Lorentz invariant [3], for example because of Lorentz contraction and mass increase the wavelength of particles changes relative each other, and it is already absolutely different particle in comparison with the moment of entanglement, due to both particles cannot be described by the same wavefunction. The absence of entanglement is in agreement with quantum mechanics, because it does not allow simultaneous measurement of conjugate quantities, which are pairs of observables of a single elementary particle. In fact, relativistic effects substitute instant reduction of wave function.

Moreover, if we increase enough the radial speed, the action of relativistic effects again disappears and instant reduction of wave function reappears. Thus, the radius of quantum teleportation depends on the speed, the more is the speed, the more is the radius (as for case of hole teleportation). Since the influence of relativistic effects begin at great (relativistic) speed, then the radius of green zone for quantum teleportation using massive entangled particles will be larger than for hole teleportation.

Conclusions

There are three important distances (barriers) for quantum teleportation as anthropic barrier (1 - 100 parsec), green sphere (1 – 1000 parsec) and Hubble sphere. Whereas first two barriers we can theoretically overcome, the Hubble sphere is ultimate, fundamental and insuperable barrier for both methods of teleportation.
Since fundamental laws limit the radius of quantum teleportation, new definition of quantum teleportation may be as:
Quantum teleportation, or entanglement-assisted teleportation is a technique that transfers a quantum state up to finite distance Rg (green zone) but not further than Hubble sphere, using a distributed entangled state and the transmission of some classical information.
The radius of hole teleportation depend on speed and is limited by green, yellow and red zones because hole teleportation is supernalogue of uniform rectilinear motion. Since quantum teleportation in the same way depend on speed and is limited by green, yellow and red zones, it means that quantum teleportation also is superanalogue of uniform rectilinear motion. It means hole and quantum teleportation have the same nature, as in both methods the material object or its quantum state is transferred from one place to another, without passing through the intervening space, i.e. outside of space - time, through vacuum hole. Hole teleportation has advantage relative quantum teleportation, since it is not limited by anthropic barrier and can teleport matter and humans. Hole teleportation is a sole method able to teleport quickly humans up to distance of 13 billions of light years.

References

1. Anton Zeilinger, Rainer Kaltenbaek, Markus Aspelmeyer, Proof-of-Concept Experiments for Quantum Physics in Space, quant- ph/ 0308174 v1 29 2003
2. Daeho Lee and Ee Chang-Young, Quantum Entanglement under Lorentz Boost, arXiv:quant-ph/0308156 v2 20 May 2004
3. D. Ahn, H.-J. Lee, S.W. Hwang, M.S. Kim, “Is quantum entanglement invariant in special relativity?” quant-ph/0304119